



PHASE CHANGE BASED MEMORY DEVICE AND METHOD FOR OPERATING SAME

BACKGROUND OF THE INVENTION

Technical Field of the Invention

5 The present invention relates to a semiconductor memory device, and particularly to a semiconductor memory device utilizing phase change material.

Description of the Related Art

Memory devices have been in existence for decades to store data or other information. There are presently many different types of both volatile and nonvolatile memories. One type of nonvolatile memory is a phase change memory. Phase change memories utilize phase change materials. Phase change materials may exhibit at least two different states. The states may be called the amorphous and crystalline states. Transitions between these states may be selectively initiated. The states may be distinguished because the amorphous state generally exhibits higher resistivity than the crystalline state. The amorphous state involves a more disordered molecular or atomic structure. Generally, any phase change material may be utilized. In some embodiments, however, thin-film chalcogenide alloy materials may be particularly suitable.

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The phase change of phase change material may be reversible. Therefore, phase change material in a phase change memory may change from the amorphous to the crystalline state and may revert back to the amorphous state thereafter, or vice versa, in response to certain changes.

In effect, each memory cell may be thought of as a programmable resistor, which reversibly
5 changes between higher and lower resistance states.

In some embodiments, the phase change memory cell may be configured in any of a relatively large number of states. That is, because each state may be distinguished by a distinct resistance or resistance range, a number of resistance-determined states may be possible, thereby allowing for the storage of multiple bits of data in a single phase change memory cell.

10 A variety of phase change alloys are known. Generally, chalcogenide alloys contain one or more elements from Column VI of the periodic table.

Phase change materials in phase change memories may be programmed from a relatively low resistance (crystalline) state to a relatively high resistance (amorphous) state by applying to the phase change material being programmed a pulse of current having a voltage level greater
15 than a switching threshold voltage of the phase change material. Programming the phase change materials from the relatively high resistance state to the relatively low resistance state is performed by applying to the phase change material a pulse of current of a lesser current level, but also at a voltage greater than the switching threshold of the phase change material.

In the semiconductor industry, there is an ongoing demand for integrated circuits that are
20 smaller, faster and less expensive to manufacture. Based upon the foregoing, there is a need for memories, such as phase change memories, having improved performance.

SUMMARY OF THE INVENTION

Exemplary embodiments of the present invention overcome shortcomings with prior phase change memory devices and satisfy a significant need for a phase change memory device that is relatively fast and is less sensitive to variations in electrical operating characteristics. The phase change memory device may include an array of phase change memory cells arranged in rows and columns, with each column of memory cells being coupled to a distinct bit line. The memory device may include a reference cell coupled to a first bit line of the bit lines, and a transistor coupled between the first bit line and a reference voltage level.

Address decode circuitry selects a row of memory cells corresponding to an address value received by the phase change memory device. An addressed memory cell in the column of memory cells coupled to the first bit line, the reference cell and the transistor form a differential amplifier circuit to relatively quickly provide a data value stored in the addressed memory cell to a data output terminal of the phase change memory device. Because of the differential amplifier circuit structure, sense amplifiers and memory precharge operations are not necessary.

BRIEF DESCRIPTION OF THE DRAWINGS

A more complete understanding of the system and method of the present invention may be obtained by reference to the following Detailed Description when taken in conjunction with the accompanying Drawings wherein:

Figure 1 is a block diagram of a memory device according to an exemplary embodiment of the present invention;

Figure 2 is a schematic of a portion of the memory device of Figure 1;

Figure 3 is a flow chart illustrating an operation of the memory device of Figure 1; and

Figure 4 is a block diagram of an electronics apparatus or system including the memory device of Figure 1.

DETAILED DESCRIPTION OF THE EXEMPLARY EMBODIMENTS

5 The present invention will now be described more fully hereinafter with reference to the accompanying drawings in which exemplary embodiments of the invention are shown. This invention may, however, be embodied in many different forms and should not be construed as being limited to the embodiments set forth herein. Rather, the embodiments are provided so that this disclosure will be thorough and complete, and will fully convey the scope of the invention to
10 those skilled in the art.

Referring to Figures 1 and 2, there is shown a memory device 1 according to an exemplary embodiment of the present invention. Memory device 1 may include an array of memory cells 2 arranged into rows and columns. Each row of memory cells 2 may be coupled to a distinct word line 3, and each column of memory cells may be coupled to a distinct bit or data
15 line 4. Each memory cell 2 may include a select transistor 6 and a programmable (or programmed) resistive element 8 coupled in series therewith (Figure 2). Select transistor 6 may be a field effect transistor as illustrated in Figure 2, but it is understood that select transistor 6 may be another type of transistor, such as a bipolar transistor. Resistive element 8 may be electrically programmable or programmed and be formed of a chalcogenide composition. It is
20 understood that resistive elements 8 may have a different composition and/or structure that allows for programmability, particularly electrical programmability.

Memory device 1 may further include address decode circuitry 10 for receiving an address value and selecting a row of memory cells 2 based upon the received address value. Address decode circuitry 10 may drive the word line 3 corresponding to the received address value to a first voltage level that activates the select transistors 6 of memory cells 2 in the addressed row, and drive the other word lines 3 to a second voltage level that deactivates the select transistors 6 of memory cells 2 in the rows not addressed. Further, address decode circuitry 10 may include circuitry that couples one or more bit lines 4 corresponding to the received address value to the data input and/or data output terminals of memory device 1. For example, address decode circuitry 10 may include multiplexing circuitry for coupling a bit line 4 to a data input and/or data output terminal of memory device 1. The particular implementation of address decoding circuitry 10 is known in the art and will not be described in greater detail for reasons of simplicity.

Memory device 1 may further include read/write drive circuitry 12 coupled to bit lines 4 and/or address decode circuitry 10, for providing to addressed memory cells 2 data values appearing at the data input terminals of memory device 1, and for providing to data output terminals of memory device 1 data values stored in addressed memory cells 2.

A control circuit 14 may be coupled to the array of memory cells 2, address decode circuitry 10, and read/write drive circuitry 12 and include timing and logic circuitry for generating timing and/or control signals for executing memory read and memory write operations.

As stated above, each memory cell 2 may include a select transistor 6 and a programmable resistive element 8 coupled in series therewith. Figure 2 illustrates a portion of the array of memory cells 2 and its interrelationship with other circuitry in memory device 1. Specifically, Figure 2 shows a column of memory cells 2 with each memory cell 2 in the column being coupled to a different word line 3 (in Figure 2, the column of memory cells 2 has been rotated 90 degrees for clarity purposes). Each memory cell 2 may include a resistive element 8 connected in series with a select transistor 6. The select transistor 6 of each memory cell may be coupled between the bit line 4 and the corresponding resistive element 8.

Each bit line 4 may be coupled to a transistor 21. Each transistor 21 may have a first conduction (drain) terminal coupled to a bit line 4, a second (source) terminal coupled to a reference voltage level, such as ground, and a control terminal. The control terminal of transistors 21 may be driven by a control signal generated by control circuit 14 so that transistors 21 are activated (i.e., turned on) during a memory read operation and deactivated (turned off) during a memory write operation. Each bit line 4 is coupled to a reference cell 23. Reference cell 23 may include a select transistor 24 connected in series with a resistive element 25. Select transistor 24 may be coupled between resistive element 25 and the corresponding bit line 4. The control terminal of select transistor 24 may be coupled to an output of read/write circuitry 12 or control circuit 14 so that select transistor 25 may be activated during a memory read operation and is deactivated during a memory write operation.

Resistive element 25 of reference cell 23 may have a certain resistance value that is between the possible resistance values of resistive elements 8. Resistive element 25 may be, for

example, programmable or programmed and constructed from a composition from which resistive elements 8 are constructed, such as from a chalcogenide composition. Alternatively, resistive element 25 may have a different structure or composition.

Memory device 1, and particularly the array of memory cells 2, may include a plurality of load elements. Referring again to Figure 2, each column of memory cells may be coupled to a first load element 27. Specifically, each load element 27 may be a diode-connected transistor, such as a p-channel transistor, and be coupled between the memory cells 2 in the column and a second reference voltage level V_{cc} . Each reference cell 23 may be coupled to a second load element 29. Each load element 29 may be a transistor coupled between the second reference voltage level V_{cc} and the corresponding reference cell 23. The control (gate) terminal of second load element 29 may be coupled to the control (gate) terminal of first load transistor 27. In this way, each bit line 4 may be associated with a distinct pair of first and second load elements. It is understood that load elements 27 and 29 may have a different structure.

According to the exemplary embodiment of the present invention, an addressed memory cell 2 serves to form part of a differential amplifier circuit during a read operation. In particular, the addressed memory cell 2, transistor 21 and reference cell 23 form a differential amplifier circuit with first load element 27 and second load element 29 during a memory read operation. Transistor 21 serves as the current source for the differential amplifier circuit. The output of the differential amplifier circuit may be taken, for example, at the node connecting second load element 29 to resistive element 25 of reference cell 23. The difference in resistance values between the resistive element 8 of the addressed memory cell 2 and the resistive element 25 of

the reference cell 23 determines the voltage level appearing at the output of the differential amplifier. The operation of the differential amplifier circuit will be described in greater detail below.

5 The formation of a differential amplifier circuit during a memory read operation from the above-identified elements advantageously improves speed (i.e., shorter read access times). In addition, the formed differential amplifier is relatively less sensitive to resistance value variations of resistive elements 8 and 25. Further, the differential amplifier formed by transistor 21 is relatively less sensitive to variations in bias current levels. Still further, the differential amplifier structure renders precharge operations at the beginning of a conventional memory
10 access operation unnecessary. Moreover, the memory architecture described above is relatively low power and consumes little current.

As stated above, read/write drive circuitry 12 may provide to data output terminals of memory device 1 data values stored in addressed memory cells 2 during memory read operations, and provide to addressed memory cells 2 data appearing at data input terminals of
15 memory device 1 during memory write operations. Read/write drive circuitry 12 may include read drive circuitry 31 having an input coupled to the output of the above-described differential amplifier circuit, and an output coupled to the data output terminals of memory device 1. Read drive circuitry 31 may be designed so that the input switching threshold voltage thereof is between the two (or more) possible output voltage levels of the differential amplifier circuit. For
20 example, the input switching threshold voltage of read drive circuitry 31 may be between a first voltage level appearing at the differential amplifier output corresponding to a logic high data

value being stored in the addressed memory cell 2, and a second voltage level appearing at the output corresponding to a logic low data value stored in the addressed memory cell 2. Read drive circuitry 31 may receive a control signal from control circuit 14 and/or address decode circuitry 10 so that data values are placed upon the data output terminals of memory device 1 at certain times, such as towards the end of a memory read operation. It is understood that read drive circuitry 29 may have any of a number of different circuit implementations.

The read/write drive circuitry 12 may further include write drive circuitry 33 having an inputs coupled to the data input pins of memory device 1 and an outputs coupled to bit lines 4 associated with addressed memory cells 2. During a memory write operation, write drive circuitry 33 may receive the data value(s) to be stored in memory device 1, and drive the bit line(s) 4 associated with addressed memory cell(s) 2 to a voltage level corresponding to the data value(s). With a bit line 4 having a predetermined voltage level applied thereto, and noting the coupling of the addressed memory cells 2 to the second reference voltage level V_{cc} , a predetermined voltage appears across and a predetermined current flows through the resistive element 8 of the addressed memory cell 2 sufficient to cause the state of resistive element 8 to be in the state having the desired resistance value. Write drive circuitry 33 may include circuitry for driving bit lines 4 to any of a number of different voltage levels for programming resistive elements 8 to any of a number of different resistance values.

The operation of memory device 1 will be described with reference to Figure 3. It is understood that the steps illustrated in Figure 3 are not limited to the particular order shown. It is

further understood that at least some of the steps illustrated in Figure 3 may occur substantially simultaneously.

In performing a memory read operation, an address is provided to memory device 1 along with necessary control signals (RD/WR, CE, etc.). In response, memory device 1 selects a word line 3 corresponding to the received address, by driving the word line 3 to a voltage to activate select transistors 6 of memory cells 2 coupled thereto, while driving the other word lines 3 to a second voltage level to deactivate select transistors 6 of memory cells 2 in other rows. Select transistors 24 of reference cells 23 are also similarly activated and deactivated. Around this time, transistors 21 are activated. Each transistor 21 may be activated, or alternatively only those transistors 21 coupled to addressed memory cells 2 are activated.

At this point, a differential amplifier circuit is formed for each column corresponding to an addressed memory cell 2. Each differential amplifier circuit is formed by the memory cell 2 in the addressed row, transistor 21 and reference cell 23, along with first load element 27 and second load element 29. For each differential amplifier circuit, the voltage appearing and its output will be based upon the resistance value of resistive element 8 in the addressed memory cell 2. In the event the resistance value of resistive element 8 had been previously programmed to be greater than the resistance value of resistive element 25 in the corresponding reference cell 23, more current passes through second load element 29 and reference cell 23, resulting in the voltage at the output of the differential amplifier circuit being at a relatively high voltage level. Conversely, in the event the resistance value of resistive element 8 had been previously programmed to be less than the resistive value of resistive element 25 of the corresponding

reference cell 23, less current passes through second load element 29 and reference cell 23, resulting in the voltage appearing at the output of the differential amplifier circuit being at a relatively low voltage level. Read drive circuitry 31 receives the output of the differential amplifier circuit and drives a data output terminal of memory device 1 to a logic level
5 corresponding to the output voltage of the differential amplifier circuit.

In performing a memory write operation, address and data values are provided to memory device 1 along with necessary control signals (RD/WR, CE, etc.). In response, memory device 1 selects a word line 3 corresponding to the received address, by driving the word line 3 to a voltage to activate select transistors 6 of memory cells 2 coupled thereto, while driving the other
10 word lines 3 to a second voltage level to deactivate select transistors 6 of memory cells 2 in other rows. Both transistor(s) 21 and select transistor 24 of reference cell(s) 23 are deactivated during the memory write operation. Next, write drive circuitry 33 may drive each bit line 4 associated with the received address to a predetermined voltage level that corresponds to the data value to be stored. With bit line 4 being at the predetermined voltage level, a predetermined voltage is
15 applied across and a predetermined current flows through resistive element 8 of the addressed memory cell 2 such that resistive element 8 is placed in (or remains in) the desired state. For example, resistive element 8, being a chalcogenide resistive element, may be placed in the amorphous state or the crystalline state. In the event each memory cell 2 is capable of storing more than two different bit values, resistive elements 8 may be placed in a plurality of different
20 amorphous and crystalline states, with each such state corresponding to a distinct resistance value (or range thereof). The particular state of resistive element 8 determines the resistance

thereof. Once resistive element 8 of the addressed memory cell(s) 2 is placed in the desired state, write drive circuitry 33 may remove the voltage appearing on bit line(s) 4. At this point, the addressed memory cell(s) 2 have been written as desired.

It has been observed that memory cells 2 may be written to more effectively by, prior to or at the beginning of each memory write operation, initially placing by write drive circuitry 33 an intermediate voltage on the appropriate bit lines 4 while the select transistors 6 of addressed memory cells 2 are activated. The intermediate voltage may be between the voltage level necessary to be placed on bit line 4 to program a logic high value, and the voltage level necessary to be placed on bit line 4 to program a logic low value. Thereafter, write drive circuitry 33 may place onto the bit lines 4 corresponding to the addressed memory cells 2 voltage levels corresponding to the desired data values to be stored in the addressed memory cells 2.

It is understood that memory device 1 may be included in many different electronics devices or systems. Figure 4 shows a block diagram of an apparatus or system 40 having therein memory device 1. Apparatus 40 may be a communications device, such as a hand-held wireless telephone, a computer, etc. Apparatus 40 may include a processing element 42 having address output terminals coupled to address input terminals of memory device 1, data output terminals coupled to data input terminals of memory device 1 and data input terminals coupled to data output terminals of memory device 1. Control signals may be provided to memory device 1 by processing element 42 or a memory controller (not shown) for controlling execution of memory access operations.

The invention being thus described, it will be obvious that the same may be varied in many ways. Such variations are not to be regarded as a departure from the spirit and scope of the invention, and all such modifications as would be obvious to one skilled in the art are intended to be included within the scope of the following claims.